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Soil and Water Conservation Technologies: A Buffer against Production Risk in the Face of Climate Change?

Insights from the Nile Basin in Ethiopia

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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Contents

List of Tables

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ABSTRACT

This study investigates the impact of different soil and water conservation technologies on the variance of crop production in Ethiopia to determine the risk implications of the different technologies in different regions and rainfall zones. Given the production risks posed by climate change, such information can be used by decision makers to identify appropriate agricultural practices that act as a buffer against climate change. Using a household- and plot-level data set, we apply the Just and Pope framework using a Cobb-Douglas production function to investigate the impact of various soil and water conservation technologies on average crop yields and the variance of crop yields, while controlling for several household- and plot-level factors. Results show that soil and water conservation investments perform differently in different rainfall areas and regions of Ethiopia, which underscores the importance of careful geographical targeting when promoting and scaling up soil and water conservation technologies. We find that although soil bunds, stone bunds, grass strips, waterways, and contours all have very significant positive impacts on average crop yields in low-rainfall areas, only soil bunds have significant risk-reducing effects in these areas with low agricultural potential. We also find that irrigation and use of improved seeds have insignificant risk-reducing effects in low-rainfall areas, suggesting that—as currently implemented—these interventions may not be appropriate adaptation strategies for these environments. Regionally, in the low-rainfall areas we find significant spatial heterogeneity, with soil bunds being risk reducing in Oromiya and Amhara, and stone bunds, grass strips, and waterways being risk reducing in the Southern Nations, Nationalities, and Peoples Region. Irrigation was only risk reducing in the high-rainfall areas of Benishangul-Gumuz. These results remain robust even after controlling for the major crops grown on the plot. Results show that soil and water conservation technologies have significant impacts on reducing production risk in Ethiopia and could be part of the country's climate-proofing strategy. However, results also show that one-size-fits-all recommendations are not appropriate given the differences in agro-ecology and other confounding factors.

Keywords : Just and Pope, risk increasing, risk reducing, Ethiopia, stone bunds, soil bunds, waterways, grass strips, contours, soil and water conservation, low-rainfall areas, high-rainfall areas, climate change

ABBREVIATIONS AND ACRONYMS

SWC	soil and water conservation
FGLS	feasible generalized least squares
FIML	full information maximum likelihood
BG	Benishangul-Gumuz
SNNPR	Southern Nations, Nationalities, and Peoples Region
EDRI	Ethiopian Development Research Institute
EEPFE	Environmental Economics Policy Forum for Ethiopia
OLS	ordinary least squares
VIF	variance inflation factors

1. INTRODUCTION

Awareness of climate change and global warming has dramatically increased among scientists, policymakers, and the general public (Nordhaus 1992, 2007; IPCC 2001, 2007; Crutzen 2002; Walther et al. 2002; Parmesan and Yohe 2003; Root et al. 2003). Agriculture in developing countries is one of the sectors that is most vulnerable to the negative impacts of climate change (Rosenzweig and Parry 1994; Reilly et al. 1996; Reilly and Schimmelpfennig 1999; Kates 2000; McGuigan et al. 2002; Kurukulasuriya et al. 2006; Seo and Mendelsohn 2008), and failure of farmers to adapt to climate change would likely have significant negative effects (Mendelsohn et al. 1994; Rosenzweing and Hillel 1998; El-Shaer et al. 1997). Given Ethiopia's dependence on natural resources and agriculture, any adverse effects of climate change on the agricultural sector would pose great risks to economic growth and livelihood in the various regions of the country.

The identification of adaptation options can help farmers to maximize future income under new climate conditions (Seo and Mendelsohn 2008), supporting poverty eradication and sustainable development. Promotion of soil and water conservation (SWC) technologies has been suggested as a key adaptation strategy for countries in the developing world, particularly in sub-Saharan Africa to mitigate growing water shortages, worsening soil conditions, and drought and desertification (Kurukulasuriya and Rosenthal 2003).

Although SWC technologies are generally low-cost interventions, they can still be too risky for very low-income, risk-averse households, which are typical in rural Ethiopia (Dercon 2004; Yesuf and Bluffstone 2007). Thus, in the adoption of technologies, farmers consider not only impacts on crop yields but also risk effects (Yesuf 2004; Shively 2001; Shiferaw and Holden 1999; Kassie et al 2008). SWC techniques are used in many areas to adapt to the drier, degraded conditions brought on in part by changes in climate. According to our household survey data, more than 30 percent of farmers took up SWC measures in response to climate change perceived as changes in temperature and rainfall over the last 20 years. This finding from our household survey suggests that farmers are using SWC technologies as one of the adaptation or mitigating options to cope with climate change, which is also one of the climate change micro-level adaptation investments recommended by the CEEPA (2006) for Ethiopia. This study investigates the risk implications of various SWC technologies for crop production in Ethiopia using the parametric stochastic production function framework of Just and Pope (1978). The analysis identifies the risk-increasing and risk-reducing effects of different SWC technologies on crop production in the different agro-ecological environments of the Ethiopian Nile basin to isolate which technologies are best suited to particular regions and agro-ecological niches. This empirical evidence can help improve geographical targeting of soil conservation techniques by policymakers, extension agents, nongovernmental organizations, and other development agencies as part of an effort to promote adaptation to climate change at the farm level.

The study also contributes to the very limited local and international literature linking SWC to production risk. Several studies have assessed the impact of crop varieties and inorganic fertilizer on the mean and variance of crop yields (Just and Pope 1979; Antle 1987; Traxler et al 1995; Smale et al. 1998; Kim and Chavas 2003); but few have investigated the risk effects of SWC technologies (Shively 1998; Byiringiro and Reardon 1996; Kaliba and Rabele 2004; Kassie et al. 2008).

The remainder of the paper is organized as follows: Section 2 provides the theoretical framework of the Just and Pope stochastic estimation that has been used in the analysis. Section 3 describes the study area, data, sampling procedures, estimation procedures, variables used, and econometric diagnostics used. Section 4 presents the descriptive and econometric results and provides a discussion of these results. Section 5 concludes with recommendations arising from the empirical analysis.

2. THEORETICAL FRAMEWORK

In the study, the Just and Pope stochastic production frontier framework (1978, 1979) is used to estimate the effects of SWC technologies on both the mean and the variance of the value of crop production per acre in the low- and high-rainfall areas of Ethiopia. The Just and Pope parametric approach allows yield-enhancing inputs to have either a negative or a positive effect on the variance of yield by relating the variance of output to explanatory variables in a multiplicative heteroskedastic regression model. The stochastic production function is represented as $y = g(\mathbf{x}, \mathbf{v})$, with y representing the output; $\mathbf{x}$, the inputs being used; and $\mathbf{v}$, the weather conditions that are unknown at planting time. Just and Pope (1978) proposed to specify $g(\mathbf{x}, \mathbf{v}) = f(\mathbf{x}) + [h(\mathbf{x})]^{1/2}\, e(\mathbf{v})$, where $h(\mathbf{x}) > 0$ and $e(\mathbf{v})$ is a random variable with mean zero and variance $h(\mathbf{x})$). This implies that $f(\mathbf{x})$ represents the mean production function, and $h(\mathbf{x})$ is the variance of output, where $E(y)= f(\mathbf{x})$ and $Var(y) = Var(e)\, h(\mathbf{x}) = h(\mathbf{x})$. Given $\partial Var(y)/\partial \mathbf{x} = \partial h/\partial \mathbf{x}$, it follows that $\partial h/\partial \mathbf{x} > 0$ identifies inputs x that are risk increasing, and $\partial h/\partial \mathbf{x} < 0$ identifies inputs that are risk decreasing. Note that e(v)[h(x)]. With mean zero and variance h(x), 1/2 behaves like an error term. This reflects the fact that the Just-Pope specification corresponds to a regression model with heteroskedastic error term. After choosing a parametric form for $f(\mathbf{x})$ and $h(\mathbf{x})$, Just and Pope proposed estimating the model either by using a three-stage feasible generalized least squares (FGLS, also called three steps) or by full information maximum likelihood (FIML) estimating f(X) and h(X) functions simultaneously, with the latter estimator being more efficient than the FGLS.

The Just and Pope framework has been widely used in previous studies (Smale et al. 1998; Widawsky and Rozelle 1998; Di Falco and Perrings 2005). It is applied in this study to investigate the effects of SWC technologies at the plot level on crop production. This analysis provides information on the risk effects of these investments across the varying rainfall conditions of the Nile basin in Ethiopia.

3. STUDY AREA, DATA, AND ECONOMETRIC ESTIMATION

Study Area

Data for this study were collected for the Nile basin within Ethiopia covering five regions: Tigray, Amhara, Oromiya, Benishangul-Gumuz (BG), and the Southern Nations, Nationalities, and Peoples Region (SNNPR). Amhara is the biggest region in the Nile basin of Ethiopia, covering 38 percent of the total area, followed by Oromiya (24 percent), BG (15 percent), Tigray (11 percent), and SNNPR (5 percent), according to the Ethiopian Ministry of Water Resources (1998).

Soil and Water Conservation Technologies Used in Ethiopia

Typical SWC technologies used in Ethiopia include soil bunds, stone bunds, grass strips, waterways, trees planted at the edge of farm fields, contours, and irrigation (chiefly water harvesting) (Table 1). Both soil and stone bunds are structures built to control runoff, thus increasing soil moisture and reducing soil erosion. Considering it is costly to protect wide areas of land with soil and stone bunds and difficult to construct continuous bunds, alternative methods of erosion control are being employed as well, including grass strips and contour leveling, sometimes with trees or hedgerows. Grass strips reduce runoff velocity, allowing for water to infiltrate and trap sediments. Waterways help to direct precipitation flows along specified pathways in farm fields. Water-harvesting structures include dams, ponds, and diversions to ensure water availability during the dry season.

Table 1. Proportion of plot-level soil conservation structures by region and rainfall regimes

Variable	Soil bunds	Stone bunds	Grass strips	Waterways	Trees	Contours	Other	Irrigation
By region								
Tigray	0.63	0.16	0.06	0.00	0.03	0.00	0.00	0.01
Amhara	0.16	0.17	0.01	0.36	0.04	0.01	0.01	0.04
Oromiya	0.25	0.06	0.02	0.25	0.07	0.02	0.00	0.04
BG	0.06	0.01	0.08	0.55	0.04	0.08	0.00	0.04
SNNPR	0.00	0.01	0.01	0.02	0.10	0.00	0.00	0.02
By rainfall regime								
Low rainfall	0.25	0.12	0.03	0.15	0.05	0.02	0.00	0.02
High rainfall	0.21	0.10	0.02	0.41	0.06	0.03	0.01	0.05

Data

The data used in this study were collected between December 2004 and November 2005 by the Ethiopian Development Research Institute (EDRI) and the International Food Policy Research Institute (IFPRI), in collaboration with the Environmental Economics Policy Forum for Ethiopia (EEPFE) for the project Food and Water Security under Global Change: Developing Adaptive Capacity with a Focus on Rural Africa, funded by the Federal Ministry for Economic Cooperation and Development, Germany. This cross-sectional household- and plot-level survey covered 5 regions, 20 districts, 13 zones, and 20 woredas, with 50 households selected in each woreda. The study covered a total sample size of 1,000 households with 6,000 plots. For details on the sample design and sampling procedure used in the study, see Deressa et al. (2008). Historical rainfall data for the period 1951 to 2000 was provided by the IFPRI water research team's Climate Research Unit of East Anglia database (Mitchell et al. 2004; Mitchell and Jones 2005).

Estimation Procedure

The analysis involved both descriptive and econometric analyses, with the descriptive statistics involving bivariate analysis and paired t-tests for hypothesis testing. The econometric analysis followed the Just and Pope approach using the Cobb-Douglas production function described in the above theoretical framework section. As described in the theoretical framework, the econometric model being estimated is of the form y=f(X) + h(X), where f(X) is the mean function and h(X) is the variance function. We are aware of other functional forms like the trans log specification, but the focus of this paper is not on estimating the magnitude of elasticities of all inputs in the production function but on testing the qualitative risk effects of the SWC technologies after controlling for other exogenous covariates that might be correlated with output. Thus, the Cobb-Douglas functional form is sufficient to serve the purpose of this paper. Although it imposes well-known restrictions on production parameters, the Cobb-Douglas functional form is frequently used in partial productivity studies (Smale et al. 1998). Nonetheless, all functional forms impose some restrictions, and even when enough is known to specify them adequately, greater flexibility is achieved with losses in degrees of freedom and increased collinearity (Griffen et al. 1987).

We tried to estimate the Just and Pope production function using the more efficient full information maximum likelihood procedure, but we failed to achieve convergency for some estimations, especially the heterogeneous subsample estimations. To circumvent this, we used the three-stage FGLS procedure outlined by Judge et al. (1982, pp. 416–423). Following the Judge et al. procedure, in the first step we ran the mean function f(X) using ordinary least squares (OLS); in the second step we predicted the residuals and then constructed squared residuals; and in the third step we used the squared residual as the dependent variable for the variance function estimation h(X) using OLS. Our main interest is on these third-stage OLS estimates of the variance function, where a positive coefficient implies risk-increasing effects, and conversely a negative coefficient implies a risk-decreasing effect of the input on crop output.

Variables and Econometric Diagnostics

Our analysis is implemented at the plot level because the focus of the study is on SWC technologies that were observed at the plot level and our dependent variable was also measured at the same level. This level of analysis is advantageous because it captures more spatial heterogeneity and also helps to control for plot-level covariates that condition crop production and hence help to minimize the omitted variable bias that would confound household-level analysis.

The dependent variable for our Cobb-Douglas specification was expressed as value of crop production per hectare, which is a better representation than yield because some plots had intercropping with more than one crop, making estimation of single crop-production functions difficult. This approach of aggregating all crops on a plot into a single measure of value of crop production per acre rather than using individual crop yields has been used in many previous plot-level-based microeconometric studies in Ethiopia and sub-Saharan Africa (Pender and Gebremedhin 2007; Pender et al. 2001, 2004 Nkonya et al. 2004, 2005, 2008; Benin 2006; Jansen et al. 2006). We used woreda average prices to estimate aggregate crop production at the plot level; therefore, our production estimates are not affected by variations in local prices. However, we did not have lagged prices but used current prices, which might have potential problems of being correlated with proximity to markets, the price of fertilizer, and the price of seeds because we are using a cross-sectional framework.

Although the focus of this study is on SWC technologies, we also controlled for a number of explanatory variables that would be correlated with the observed plot-level crop outputs. The explanatory variables (X) we controlled for included both plot-level and household-level covariates. The plot-level covariates included plot area, biophysical characteristics (e.g., soil type, fertility status, slope, and soil depth), inputs used on the plot (e.g., draft power, fertilizers, purchased seeds, own seeds, family labor, and hired labor), land management practices used on the plot (e.g., manure and compost), and land investments on the plot (e.g., soil bunds, stone bunds, waterways, trees, contours, and irrigation). Household-level covariates included characteristics of the household head (sex, age, education). We also included an interaction term between improved seed, fertilizer, and irrigation to examine the complementarity between these technologies and in which niches they would have high payoffs. For the full-sample estimations, regional fixed effects were included to control for unobserved time-invariant characteristics that might be correlated with the dependent variable, which also mitigates the omitted variable bias problem.

The double logarithmic functional form of the Cobb-Douglas specification used in the Just and Pope framework helped to improve normality of the residuals, thus reducing problems of nonlinearity, heteroskedasticity, and sensitivity to outliers (Mukherjee et al. 1998). In all the multivariate estimations, we used the Huber-White estimator (White 1980), which is robust to heteroskedasticity of unknown form. We tested for multicollinearity using the variance inflation factors (VIF) and also by pairwise correlations. Multicollinearity was not a serious problem: the VIFs were less than 3.0 and the pairwise correlations were less than 0.5, indicating that the standard errors were not being affected by collinearity problems. Another potential problem could arise from the possible endogeneity bias of the SWC technologies. However, since these investments are long-term investments that are likely to have been on the plot long before the current period of analysis, the decisions for the farmer to have these structures on the plot will be predetermined or exogenous to the current level of production. Therefore, the endogeneity bias is not a serious problem.

4. RESULTS AND DISCUSSION

Descriptive Results

Descriptive results are presented in Tables 1, 2, and 3. Using historical rainfall data at the woreda (district) level from 1951 to 2000, we classified the woredas sampled in the Nile River basin of Ethiopia into those receiving high and low rainfall as shown in Table 2. All the woredas in the Tigray and SNNPR regions in our sample fell into the low-rainfall quantile, while those in Amhara, Oromiya, and BG regions fell into both the low- and high-rainfall quantiles (Table 2). For the woredas in Amhara, Oromiya, and BG, we found highly significant differences in mean rainfall amounts between the low- and high-rainfall quantiles (Table 3), which gave us more confidence in the classifications that were generated. As expected, Tigray appears to be the driest region among the five, and Oromiya had the highest average rainfall from 1951 to 2000.

Table 2. Classification of woredas into rainfall regimes by region

	Low	High
Tigray		
Atsbi Wenberta	X	
Endamehoni	X	
Hawzen	X	
Amhara		
Bichena	X	
Chilga	X	
Debark	X	
Kemkem	X	
Quarit		X
Wegera	X	
Oromiya		
Bereh-Aleltu	X	
Gimbi		X
Haru	X	
Hidabu-Abote	X	
Kersa	X	
Limu		X
Nunu-Kumba		X
BG		
Bambesi	X	
Sirba Abay		X
Wonbera		X
SNNPR		
Gesha-Deka	X	

Table 3. Distribution of rainfall (mm) in low- and high-rainfall woredas by region

Region	Mean-low-rainfall woredas	Mean-high-rainfall woredas	T-test (P value) Ho: No mean difference
Tigray	572 (3.2)	—	—
Amhara	883 (5.3)	1,075 (1.5)	0.000***
Oromiya	922 (2.1)	1,180 (1.4)	0.000***
BG	967 (0.6)	1,093 (0.3)	0.000***
SNNPR	1,006 (0.1)	—	—

***: The difference is statistically significant at the 1% level.
Note: Numbers in parentheses are standard errors.

Interestingly, soil bunds (63 percent) are highest on plots in the drier Tigray region than in any other region, waterways are most common on plots in the BG region (55 percent), and trees are most reported in the SNNPR region (Table 1). Overall, by region, the most common SWC investments are as follows: Tigray, soil bunds and stone bunds; Amhara, waterways and stone bunds; Oromiya, soil bunds and waterways; BG, waterways; and SNNPR, trees; as shown in Table 1. Further, descriptive analysis in Table 1 reveals that plots in low-rainfall areas have disproportionately more stone bunds and soil bunds than plots in high-rainfall areas, and those in high-rainfall areas have more waterways and irrigation. It might appear surprising that irrigation is more prevalent on plots in high-rainfall areas than in low-rainfall areas. However, irrigation requires a minimum amount of rainfall or more costly structures in low-rainfall areas. Investigation in a multivariate framework makes it possible to examine whether more returns with irrigation are realized in high-rainfall environments after controlling for confounding factors at the plot level. This descriptive evidence shows a clear spatial heterogeneity in Ethiopia in the use of SWC technologies, suggesting that different SWC investments perform differently in different regions and agro-ecological niches.

The next section describes the multivariate analysis used to assess the risk implications of the adoption of SWC technologies after controlling for other possible confounding factors.

Econometric Results

Effects of Soil and Water Conservation Technologies on the Average, and Variance of Crop Yields in Low- and High-Rainfall Areas

Econometric results are presented in Tables 4, 5, and 6 for the mean and variance functions for both the low- and high-rainfall areas in Ethiopia. As shown in Table 4, all SWC technologies considered in this study (stone bunds, soil bunds, grass strips, waterways, trees, and contours) showed positive and very highly significant impacts on crop output in the low-rainfall areas, but only waterways and trees showed strong and significant positive effects in high-rainfall areas. The finding that stone bunds and soil bunds show positive significant mean impacts on crop production only in low-rainfall areas supports the descriptive evidence that these technologies were observed more often on plots in low-rainfall areas; this is also consistent with previous studies in Ethiopia that made similar observations (Kassie et al. 2008;

Bekele 2005; Gebremedhin et al. 1999). Kassie et al. (2008) and Bekele (2005) both found stone bunds to have favorable impacts on production in low-rainfall areas. Another interesting result from the mean functions is that grass strips showed the largest significant production elasticity among the SWC technologies only in the low-rainfall areas, which supports the empirical finding by Shiferaw and Holden (2001) in their economic analysis of soil conservation in Ethiopia, where grass strips showed the highest net benefits in low-rainfall areas.

Table 4. Effects of soil conservation structures on mean and variance of crop production by rainfall regimes, mean function, and variance function estimates

Variable	Low-rainfall areas		High-rainfall areas	
Plot characteristics	Mean function	Variance function	Mean function	Variance function
Use irrigation	0.041	1.091	-0.253***	0.103
Log plot area	-0.604***	0.05	-0.592***	-0.118
Log draft power	0.151***	-0.135	0.144***	-0.244***
Soil color (cf. clay)				
Sand	-0.108	0.057	-0.08	0.191
Dark	-0.127**	0.115	0.09	0.019
Red	-0.107*	0.174	0.155***	0.180**
Other	-0.633***	0.244	-0.365	2.238
Dark red	-0.098	-0.1	-0.063	0.247
Brown	-0.036	-0.014	0.084	-0.431
Soil fertility (cf. high)				
Moderate	-0.169***	-0.027	-0.110***	0.127*
Infertile	-0.043	-0.260**	-0.228***	0.174*
Soil slope (cf. flat)				
Moderate	0.034	-0.105	-0.066*	0.131**
Steep	-0.079	-0.02	0.022	0.245
Soil depth (cf. shallow)				
Deep	0.193***	-0.14	-0.011	0.051
Moderate	0.130**	-0.062	0.082	-0.039
Land investments				
Soil bund	0.122**	-0.211**	0.076	-0.308***
Stone bunds	0.177***	-0.15	0.123*	-0.342**
Grass strips	0.334***	-0.04	0.147	-0.561***
Waterway	0.195***	0.081	0.187***	-0.402***
Trees	-0.073	-0.086	0.298***	-0.135
Contour	0.237*	0.117	-0.044	-0.321**
Other	0.038	-0.887**	-0.107	-0.362
Land management practices				
Log urea	0.023*	-0.015	0.034***	-0.045***
Log dap	-0.001	0.018	0.030***	0.012

Table 4. Effects of soil conservation structures on mean and variance of crop production by rainfall regimes, mean function, and variance function estimates (continued)

Variable	Low-rainfall areas		High-rainfall areas	
Plot characteristics	Mean function	Variance function	Mean function	Variance function
Log manure	0.018**	-0.026*	0.01	-0.012
Log compost	-0.011	0.025	0.032**	0.007
Log traditional seed	0.286***	-0.116**	0.201***	-0.158***
Log improved seed	0.212***	-0.033	0.190***	-0.132***
Fertilizer*seed*irrigation	-0.073	0.160*	0.016***	0.004
Labor endowments				
Log family men	0.085***	0.059	0.114***	-0.034
Log family women	0.045***	-0.071*	-0.037**	0.125***
Log family child	-0.009	0.060**	-0.047***	0.005
Log hired men	0.026	0.123***	0.037**	0.036
Log hired women	0.056*	0.084	-0.002	-0.05
Log hired child	0.167***	-0.367***	-0.152	0.156*
Household factors				
Sex household head (1=female)	-0.041	0.019	0.053	-0.148
Log education years of head	-0.048	-0.042	-0.113**	-0.017
Log age household head	-0.181***	0.639***	-0.205***	0.063
Regions (cf. Tigray)				
Amhara	-0.314***	0.151	-0.641***	0.088
Oromiya	-0.064	-0.317***	-0.698***	-0.135*
BG	0.343***	-0.374*	0.000	0.000
SNNPR	-0.106	-0.477***	0.000	0.000
_cons	4.435***	-1.063	5.442***	0.899**
N	2847	2847	2826	2826

*, **, ***: The difference is statistically significant at the 10%, 5%, or 1% level, respectively.

Although most of the SWC technologies are showing significant positive effects on the mean of production as discussed above in the low-rainfall areas, surprisingly only soil bunds have a significant risk-reducing effect. This explains why almost 30 percent of the plots (Table 1) have these investments and why other interventions that also have high, positive impacts on yield in these low-potential areas are used much less.

In high-rainfall, high-agricultural potential areas, most of the SWC technologies considered in this study have significant risk-reducing effects. Soil bunds, stone bunds, grass strips, waterways, and contours all have very significant and negative effects on yield variability and hence are risk-reducing in high-rainfall areas.

Although both traditional and improved seeds show significant positive effects on increasing average crop production in both low- and high-rainfall areas, they have different effects on the variance of crop production. Traditional seed is risk reducing in both low- and high-rainfall areas, while improved seed is only significantly risk reducing in high-rainfall areas. These results on the whole suggest that soil bunds and traditional seeds would be appropriate strategies to adapt to climate change in low-rainfall areas. Improved seeds, traditional seeds, stone bunds, soil bunds, grass strips, waterways, and contours appear to be promising adaptation strategies in high-rainfall areas.

Mean and Variance Effects in Low-Rainfall Areas by Region

The effects of SWC technologies vary not only by high- and low-rainfall areas, but also by region within those areas. To check for robustness of our results, we have presented results with and without controlling for the major crop type on the plot, considering crop type is likely to be endogenous. The results appear qualitatively very robust as shown in Tables 5 and 6, so the discussion will mainly follow results in Table 5. The results for low-rainfall areas show that in Amhara and Oromiya soil bunds are risk reducing, and that stone bunds are significantly risk reducing in low-rainfall areas of SNNPR. Grass strips, waterways, and trees are only risk reducing in SNNPR. Irrigation has no significant risk-reducing effects in any region in the low-rainfall areas but shows a significant risk-increasing effect in the low-rainfall areas of Tigray (Table 6) after controlling for the major crop type on the plot. The risk-increasing aspect of irrigation in low-rainfall areas seems counterintuitive considering irrigation is intended to mitigate the adverse effects of low rainfall. We have no indicators regarding the quality of irrigation in the survey. If irrigation is based on small storage, as is the case for water-harvesting structures in Tigray, then insufficient rainfall and droughts can prevent full-control irrigation, and irrigation can actually be risk-increasing. Generally, studies on water harvesting have found mixed results for Ethiopia. Reasons for failure include poor technical design; lack of water, which could be stored in dry years; inappropriate and costly placement; and lack of community sensitization—some ponds were constructed under food-for-work programs and, despite appropriate design, abandoned after these programs ended because social, economic, and management factors were inadequately integrated in the pond development system (Awulachew et al. 2005; Lemma 2007).

Table 5. Risk effects of soil conservation structures on crop production by region and rainfall regime, variance function estimates

Variance Function								
Variable	Tigray	Amhara		Oromiya		BG		SNNPR
Plot characteristics	Low	Low	High	Low	High	Low	High	Low
Use irrigation	2.855	2.478	0.357	0.138	0.031	-2.601	-0.442***	-0.122
Log plot area	0.046	0.216	-0.113	0.023	-0.143*	-0.319	-0.167	0.200***
Log draft power	0.022	-0.547	-0.605***	-0.122*	-0.207***	0.37	0.018	0.028
Soil color (cf. clay)								
Sand	-0.085	0.051	0.197	0.24	-0.331*	-0.405	-0.183	-0.347**
Dark	0.055	0.273	0.042	-0.466	-0.119	-0.267	-0.47	0.029
Red	0.069	0.482*	0.303***	-0.581**	0.032	-0.156	-0.464	0.097
Other	0.485*	-1.248**	1.582	0.126	0	0	0	0
Dark red	0	-0.33	0.236	-0.345	0	0	-0.707*	0
Brown	0	0.805	-0.426	0	0	0	0	0
Soil fertility (cf. high)								
Moderate	-0.057	0.158	0.256***	0.061	0.147	0.432	-0.035	-0.181**
Infertile	-0.118	-0.186	0.243*	0.088	0.261**	0.113	0.041	0
Soil slope (cf. flat)								
Moderate	0.006	-0.136	0.155*	-0.044	-0.038	-0.552	0.13	-0.064
Steep	-0.219	-0.097	0.365	0.025	-0.032	-0.552	0.048	-0.001
Soil depth (cf. shallow)								
Deep	-0.038	-0.035	0.101	0.194	-0.32	-0.474	0.311	-0.179**
Moderate	-0.005	-0.015	0.086	0.145	-0.391	-0.074	0.247	-0.123**
Land investments								
Soil bund	0.135	-0.481*	-0.174	-0.181*	-0.306*	0.568	-0.471**	0.000
Stone bunds	-0.163	-0.024	-0.418**	0.061	-0.387*	0.717	0.000	-0.262**
Grass strips	-0.087	0.000	-0.777***	-0.166	-0.446**	0.880**	-0.520***	-0.257***
Waterway	0.083	0.132	-0.477***	0.155	-0.1	0.63	-0.328**	-0.260*

Table 5. Risk effects of soil conservation structures on crop production by region and rainfall regime, variance function estimates (continued)

	Variance Function							
Variable	Tigray	Amhara		Oromiya		BG		SNNPR
Plot characteristics	Low	Low	High	Low	High	Low	High	Low
Trees	0.978**	-0.259	-0.659***	0.64	-0.017	0.131	-0.602***	-0.126*
Contour	0.000	-0.815	-0.602***	0.163	0.272	0.348	-0.176	0.000
Other	0.000	-1.619	-0.219	-0.393***	-0.438*	0.000	-0.577*	0.000
Land management practices								
Log urea	-0.070**	0.147	-0.016	-0.034	-0.028	0.027	-0.017	0.000
Log dap	0.065*	-0.016	-0.034	-0.014	0.077***	0.101	-0.011	-0.110***
Log manure	-0.041***	0.070*	0.011	-0.01	-0.028**	-0.058	0.024	-0.009
Log compost	0.061	-0.001	-0.001	-0.006	0	-0.021	-0.051	0.000
Log traditional seed	-0.125**	-0.119	-0.161***	-0.061*	-0.130***	-0.09	-0.119*	-0.019
Log improved seed	-0.055	-0.016	-0.130**	-0.025	-0.185***	0.041	-0.108	-0.034
Fertilizer*seed*irrigation	0.332***	0.000	0.013	0.016	-0.004	0.000	0.037	
Labor endowments								
Log family men	0.170***	-0.016	-0.054	0.000	0.026	0.477	-0.042	0.101*
Log family women	0.029	-0.260**	0.162***	0.058	0.019	-0.493	0.029	-0.036
Log family child	0.076	0.236***	-0.015	-0.128***	-0.051**	-0.147	0.037	-0.083*
Log hired men	0.132**	0.109	0.02	0.092**	0.134*	-0.513	0.04	-0.176***
Log hired women	0.007	-0.028	-0.071	0.201**	-0.339***	0.601	-0.003	0
Log hired child	0	-0.452**	0.002	-0.135	0.338***	-0.524	-0.279***	0
Household factors								
Sex household head(1=female)	0.148	-1.047***	-0.212	0.465***	0.171	0.82	0.019	0

Table 5. Risk effects of soil conservation structures on crop production by region and rainfall regime, variance function estimates (continued)

Variable	Variance Function							
	Tigray	Amhara		Oromiya		BG		SNNPR
Plot characteristics	Low	Low	High	Low	High	Low	High	Low
Log education years of head	-0.293***	1.255***	-0.166	-0.383***	0.021	0.212	0.196	-0.212***
Log age household head	0.514***	2.460***	-0.280*	0.139	0.382***	0.344	0.096	-0.052
Lograin	0.11	1.216*	-1.161	0.636	-0.788	33.916	-5.536	20.527*
_cons	-2.856	-12.807**	10.394*	-4.366	5.537	-233.837	39.926	-141.556*

Table 6. Risk effects of soil conservation structures on crop production by region and rainfall regime controlling for major crop type, variance function estimates

	Variance Functions with Major Crop Type							
Variable	Tigray	Amhara		Oromiya		BG		SNNPR
Plot characteristics	Low	Low	High	Low	High	Low	High	Low
Use irrigation	2.601*	2.51	0.372	0.094	-0.044	-2.043	-0.427***	-0.023
Log plot area	0.086	0.201	-0.111	0.039	-0.186**	-0.343*	-0.204	0.103*
Log draft power	-0.054	-0.502	-0.572***	-0.058	-0.266***	0.324	0.048	0.065
Soil color (cf. clay)								
Sand	-0.053	0.053	0.179	0.970**	-0.378**	-0.024	-0.204	-0.430***
Dark	0.033	0.295	0.071	0.422	-0.224	-0.356	-0.337	-0.058
Red	0.138	0.496*	0.312***	0.275	-0.072	-0.243	-0.369	-0.031
Other	0.502**	-1.138**	1.368	0.514	0	0	0	0
Dark red	0	-0.26	0.22	0.712	0	0	-0.493	0
Brown	0	0.806	-0.385	0	0	0	0	0

Table 6. Risk effects of soil conservation structures on crop production by region and rainfall regime controlling for major crop type, variance function estimates (continued)

	Variance Functions with Major Crop Type							
Variable	Tigray	Amhara		Oromiya		BG		SNNPR
Soil fertility (cf. High)								
Moderate	-0.078	0.118	0.230**	0.068	0.101	0.341	-0.076	-0.054
Infertile	-0.135	-0.205	0.293**	0.019	0.173	0.097	0.088	0
Soil slope (cf. flat)								
Moderate	0.028	-0.128	0.158*	-0.055	-0.118	-0.422	0.152*	-0.089**
Steep	-0.207	-0.075	0.37	-0.035	-0.159	-0.707	0.046	0.078
Soil depth (cf. shallow)								
Deep	-0.12	-0.031	0.115	0.14	-0.460*	-0.403	0.243	-0.161**
Moderate	-0.054	0.011	0.059	0.095	-0.511**	-0.089	0.206	-0.154**
Land investments								
Soil bund	0.147	-0.457*	-0.138	-0.163	-0.296*	0.49	-0.405**	0
Stone bunds	-0.146	-0.033	-0.415***	0.007	-0.423**	0.365	0	-0.183
Grass strips	-0.077	0	-0.623***	-0.248	-0.474***	0.681**	-0.366***	-0.239***
Waterway	-0.101	0.173	-0.424***	0.121	-0.117	0.514	-0.232*	-0.300**
Trees	1.086**	-0.237	-0.595***	0.686	-0.063	0.108	-0.465***	-0.085
Contour	0	-0.784	-0.584***	0.03	0.224	0.254	-0.034	0
Other	0	-1.682	-0.257	-0.465***	-0.560**	0	-0.295	0
Land management practices								
Log urea	-0.058*	0.171	-0.017	-0.034	-0.046*	0.027	0.003	0
Log dap	0.066*	-0.024	-0.027	0.013	0.068***	-0.022	-0.003	-0.103***
Log manure	-0.043***	0.074**	-0.002	0.014	-0.028**	-0.061	0.015	0.004
Log compost	0.044	-0.007	-0.024	0.005	0	0.006	-0.022	0
Log traditional seed	-0.122***	-0.103	-0.147***	-0.03	-0.204***	-0.101	-0.09	-0.017

Table 6. Risk effects of soil conservation structures on crop production by region and rainfall regime controlling for major crop type, variance function estimates (continued)

	Variance Functions with Major Crop Type							
Variable	Tigray	Amhara		Oromiya		BG		SNNPR
Log improved seed	-0.065	0.001	-0.121**	0.008	-0.259***	-0.032	-0.087	-0.008
Fertilizer*seed*irriga'n	0.376***	0	0.011	0.013	-0.004	0	0.027	
Labor endowments								
Log family men	0.175***	-0.012	-0.061	-0.033	0.053	0.448	-0.05	0.009
Log family women	0.054*	-0.260**	0.148***	0.029	0.035	-0.507	-0.02	-0.007
Log family child	0.078*	0.232***	-0.014	-0.106***	-0.054**	-0.103	0.045	-0.012
Log hired men	0.125**	0.097	0.021	0.087*	0.132*	-0.41	0.05	-0.195***
Log hired women	0.025	-0.039	-0.059	0.171**	-0.229**	0.532	-0.053	0
Log hired child	0	-0.437**	0.013	-0.073	0.171**	-0.507	-0.233***	0
Household factors								
Sex household head(1=female)	0.188	-0.956***	-0.173	0.386**	0.195*	0.58	0.01	0
Log education years of head	-0.202**	1.241***	-0.098	-0.438***	0.053	0.255	0.235*	-0.133**
Log age household head	0.557***	2.384***	-0.318*	0.043	0.318***	0.395	0.038	-0.052
Climate								
Log rain	-0.008	1.160*	-1.239	0.555	-0.729	38.330**	-5.737	16.372*
Crop type (c.f Barley)								
Teff	-0.418**	-0.266	-0.058	-0.04	0.158*	-0.058		0.023
Maize	0.667	-0.601	-0.111	0.844***	-0.256***	-0.129		0.104
Millet	-0.500***	0.21	-0.274**	-0.101	-0.347***	-0.039		0
_cons	-1.997	-12.340**	11.166*	-4.46	5.963	-264.011**	41.387	-112.643*
N	801	755	1556	704	887	245	383	342
r2	0.198	0.125	0.087	0.194	0.147	0.127	0.106	0.217

Mean and Variance Effects in High-Rainfall Areas by Region

The results for high-rainfall areas show that soil bunds are risk increasing in Oromiya and BG, while all other technologies tend to reduce production risk. Stone bunds are risk reducing in Amhara and Oromiya; grass strips are risk reducing in Amhara, Oromiya, and BG; waterways are risk reducing in Amhara and BG; trees are risk reducing in Amhara and BG; and contours are risk reducing Amhara. Irrigation has risk-reducing effects in BG.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The results of the empirical analysis show that SWC technologies have significant impacts on reducing production risk in Ethiopia and could be part of the country's climate-proofing strategy. The results also show that one-size-fits-all recommendations are not appropriate given the differences in agro-ecology and other confounding factors. Performance of these technologies is location specific, and therefore, programs aimed at promoting SWC measures as part of a strategy to adapt to climate change should acknowledge these differences.

Overall, in low-rainfall areas soil bunds appear to be investments with a risk-reducing effect on production; while stone bunds are risk reducing in low-rainfall areas of Amhara and Oromiya. In addition, grass strips, waterways, and trees, which are less capital intensive, also appear to have a risk-reducing effect in these dry environments, as shown in the SNNPR and BG regions. Contours, irrigation, and improved seed technologies do not seem to have any significant effects on reducing production risk in these areas with low agricultural potential and therefore should not be promoted as part of an effort to adapt to climate change.

In high-rainfall areas, most soil conservation technologies appear to have positive effects on reducing production risk, with some variation by region. Irrigation, traditional seed, and improved seed also have good potential as adaptation strategies for mitigating climate-change effects through reducing production risk in these areas, which have high agricultural potential.

The results have demonstrated that although most of the SWC investments have significant, positive mean impacts on yields in low-rainfall areas, they do not all show a correspondingly similar risk-reducing effect, which might explain their low adoption rates in these areas. Therefore, promotion of adaptation strategies should be location specific and mindful of spatial and risk-related differences in Ethiopia.

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